Towards an integrated understanding of late Holocene fault activity in western Puerto Rico: Offshore geophysical survey: Collaborative Research University of North Carolina, Wilmington and UTIG

Annual Project Summary

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Investigations Undertaken

The island of Puerto Rico is located within a diffuse and complex plate boundary zone between the North American and Caribbean plates. Seismicity data and marine geophysical and geodesy studies of the easternmost portion of the North American-Caribbean plate boundary suggest that Puerto Rico and the Virgin Islands to the east are currently behaving as part of the stable Caribbeam plate and are moving in a ENE direction (070°) at a rate of 19-20 mm/yr relative to North America (Jansma et al, 2000; Mann et al.,in press). On the basis of side-scan sonar imagery and single-channel seismic data Grindlay et al.(1997) and Van Gestel et al.(1998; 1999) have identified extensive normal faulting of the Oligocene to early Pliocene carbonate platform in the central and western portion of the Mona Passage, the marine strait separating Puerto Rico and the Dominican Republic. This localized extension of the platform strata reflects the differential eastward relative motions of the island of Puerto Rico and Hispaniola. Recently published GPS geodetic measurements collected during a 10-year period in the region support these findings and suggest the amount of differential motion is about 5 mm/yr (Dixon et al., 1998; Lopez et al., 1999, Jansma et al., 2000).

Most geophysical and geological data sets including GPS geodesy indicate that the deformation zone extends onshore within western Puerto Rico (cf. van Gestel et al., 1998; Jansma et al., 2000). The onshore and offshore region of southwestern Puerto Rico is one of the most seismically active regions near the island of Puerto Rico. During the past five years alone over 70 earthquakes with a magnitude of 3.0 or greater have been recorded by the local seismic network in the southwestern region of Puerto Rico (Seismic Network, 2000). This seismic activity associated with deformation along the active northeastern North America-Caribbean plate boundary poses a serious threat to the growing population on the island of Puerto Rico, in particular the rapidly developing western and southern regions. Studies of seismicity and associated hazards in western Puerto Rico have identified areas onshore of active and historically significant seismic risk (e.g. Moya and McCann,1992; Ascenio, 1980). While these studies provided a general description of potential seismic hazards onshore, an understanding of the distribution and nature of active fault structures offshore has been lacking.

Existing multichannel seismic profiles offshore western and southern Puerto Rico, collected by Western Geophysical in 1972, show numerous east-west trending normal and strike-slip faults offsetting Oligocene-Pliocene age carbonates and the underlying Cretaceous basement however the interpretation did not distinguish between active and inactive faults (Fig. 1). A systematic high-resolution sidescan sonar mapping and seismic profiling survey of the shallow insular shelf of Puerto Rico was conducted by Grindlay, Abrams and Mann in May 2000, to provide a better understanding of the seismogenic potential of the submarine deformation zone. During a 10-day period, over 728 km of along-track single-channel and sidescan sonar data were collected. All of the sidescan sonographs have been filtered, slant range corrected, bottom corrected, destriped and beam angle corrected before being placed into a georeferenced digital mosaic. All of the seismic profiles have been processed with the following parameters: spherical divergence correction, spectral whitening, time variant band-pass filtered at 200-2400Hz trace mixing, water bottom mute and a 10 msec AGC.

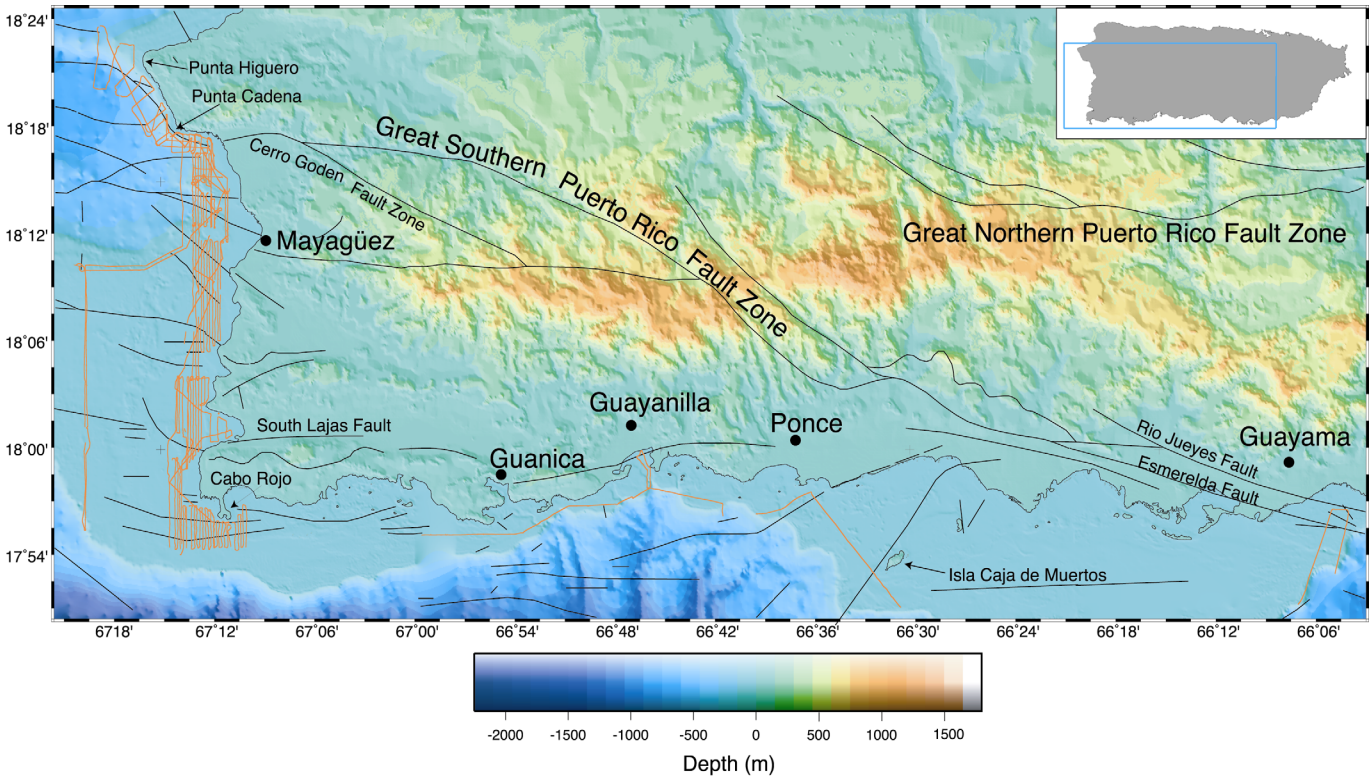


Figure 1. A DEM of Puerto Rico and insular shelves showing the location of the May 2000 marine geophysical survey (orange lines). Black lineations represent faults interpreted by Furgo, Inc. and Western Geophysical Co. from multichannel seisimc data collected in 1972. The interpretation did not distinguish between active and inactive faults. Comparison of these fault locations with high-resolution sidescan sonar and sub-bottom profile data collected in May 2000 show that many of the faults do not break surface sediments. The fault locations do, however provide information about the past tectonic history of the region and locate regions of potential crustal weakness where reactivation could occur.

Preliminary analyses of these data identify three zones of active deformation within the survey area:

- extension of the Cerro Goden fault zone which lies offshore Bahia de Anasco of western Puerto Rico. Observations of linear offsets in seafloor features and an unsedimented submarine ridge immediately south of the mountains of La Cadena de San Francisco are consistent with recent activity along the Cerro Goden fault zone (Lao et al., 2000). The submarine ridge parallels the coastline as it curves from a W to NW trend at Punta Cadena, possibly extending to the Desecheo Ridge, the southern limit of the Mona Rift Zone (Fig. 2).

- extension of the Algarrobo fault zone offshore and folding and vertical offsets in recent sediments blanketing the Oligocene-Pliocene age carbonate platform within Bahia de Mayagüez (Fig. 3).

- southeast and northeast trending lineaments on the southern insular shelf offshore, which are possible active extensions of the Great Southern Puerto Rico Fault Zone (Fig. 4).

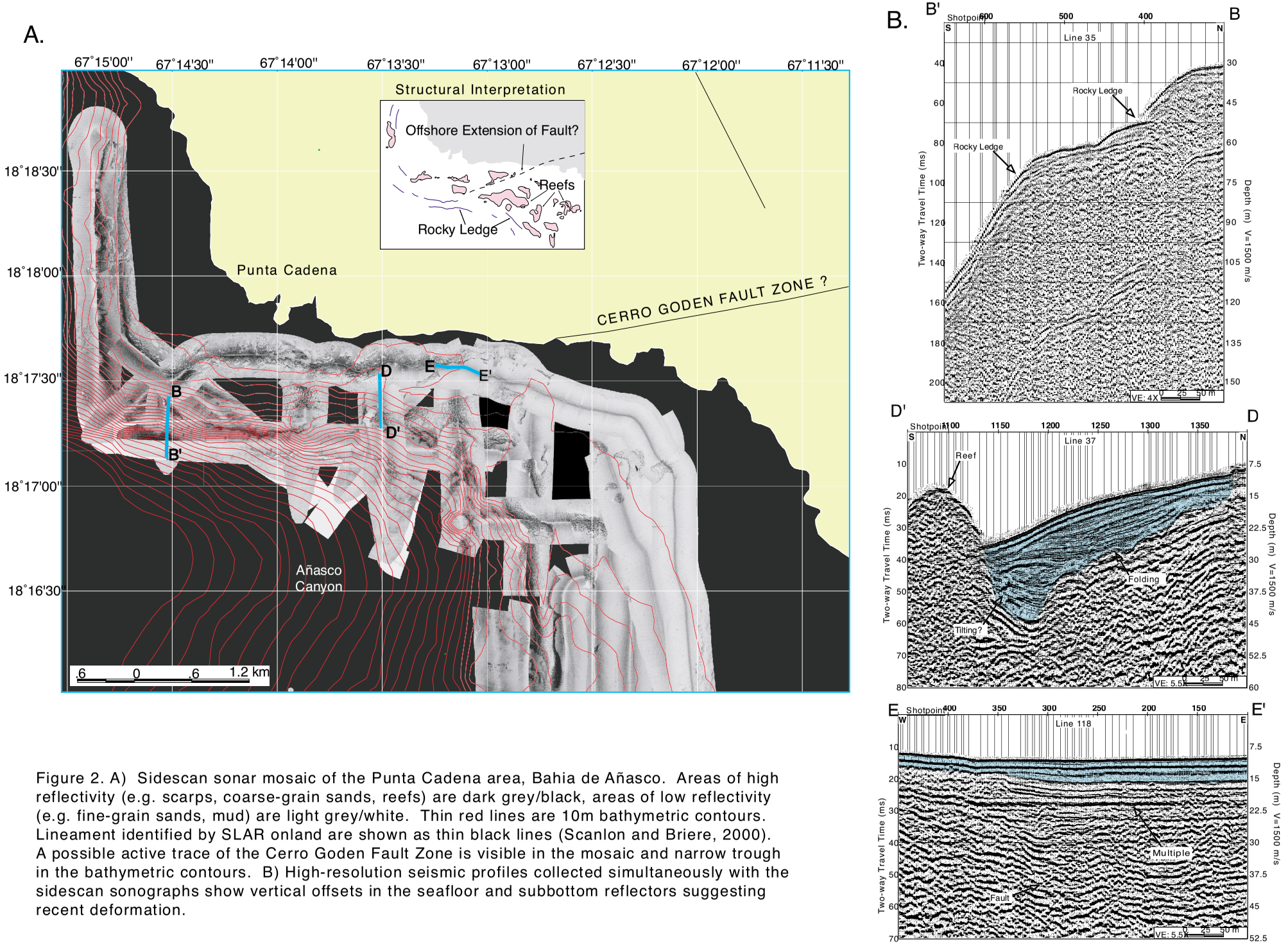
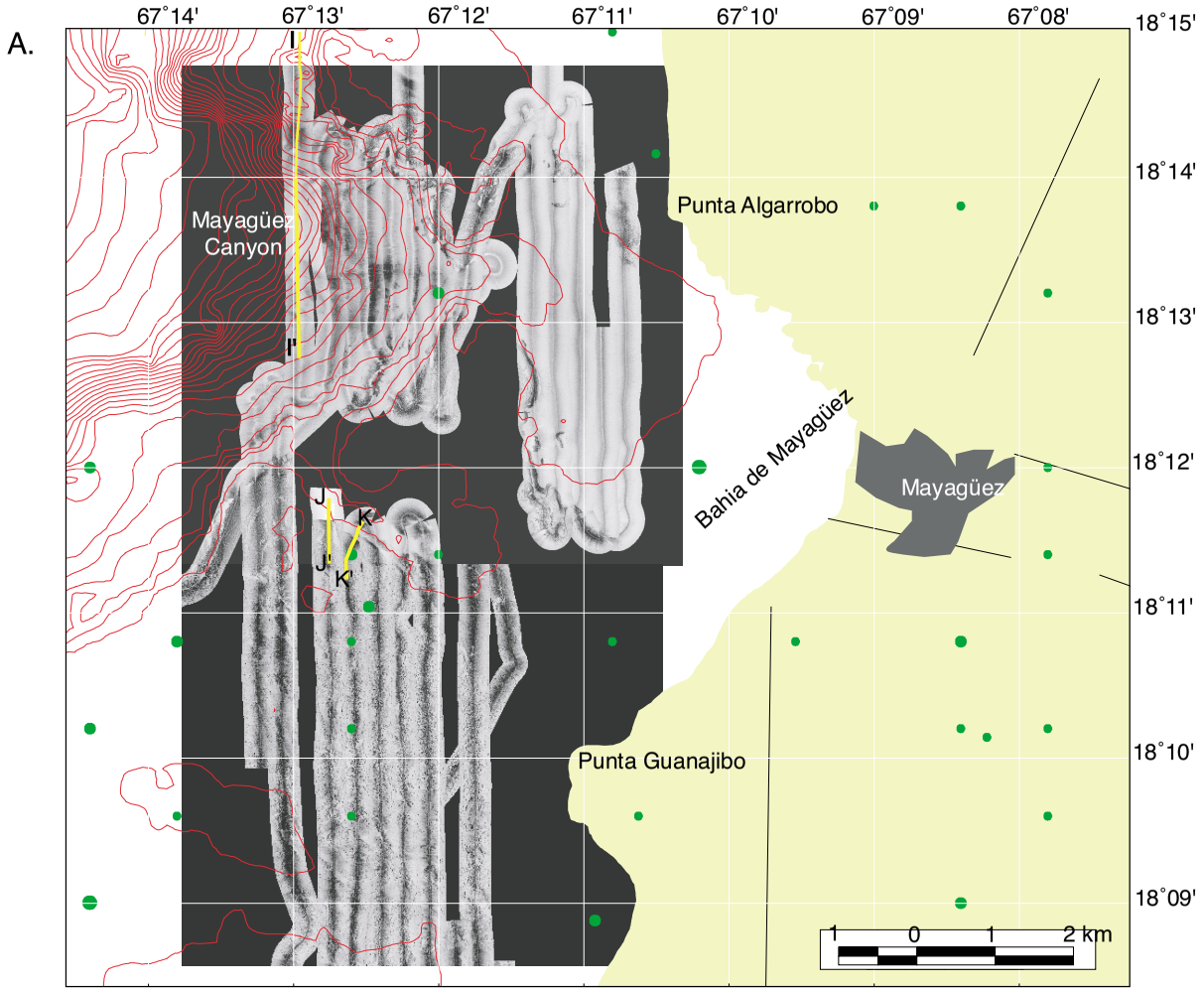
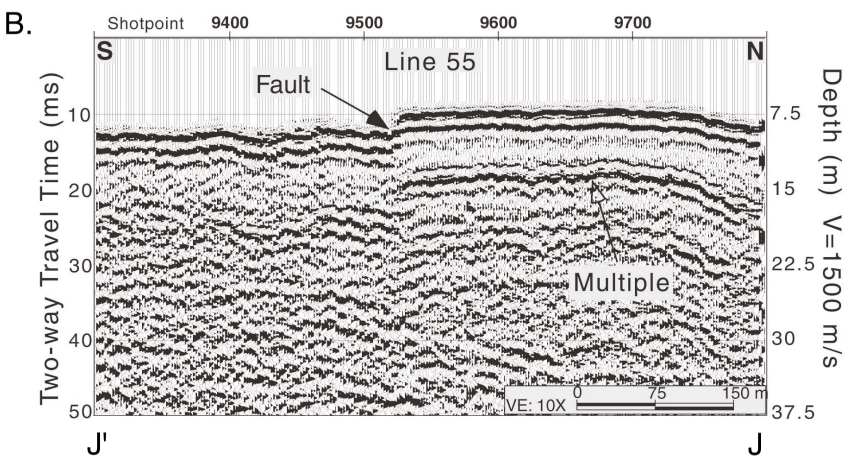


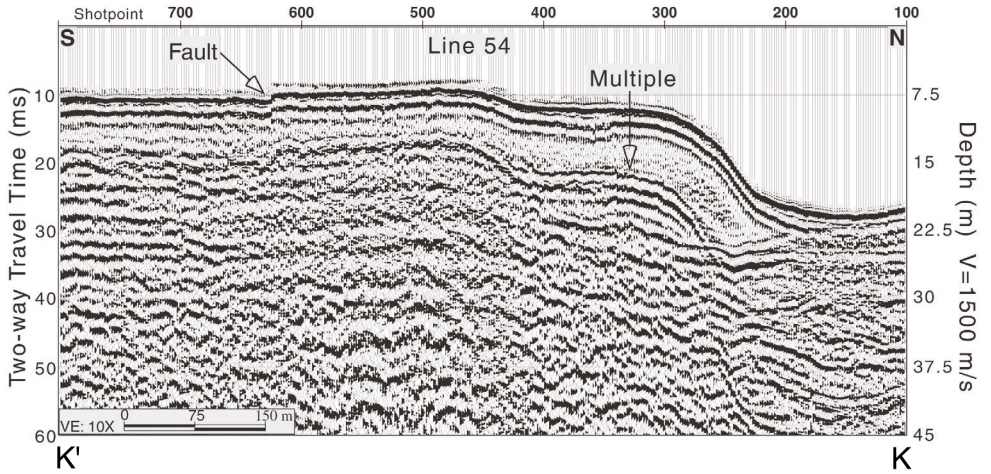
Figure 2. A) Sidescan sonar mosaic of the Punta Cadena area, Bahia de Añasco. Areas of high reflectivity (e.g. scarps, coarse-grain sands, reefs) are dark grey/black, areas of low reflectivity (e.g. fine-grain sands, mud) are light grey/white. Thin red lines are 10m bathymetric contours. Lineament identified by SLAR onland are shown as thin black lines (Scanlon and Briere, 2000). A possible active trace of the Cerro Goden Fault Zone is visible in the mosaic and narrow trough in the bathymetric contours. B) High-resolution seismic profiles collected simultaneously with the sidescan sonographs show vertical offsets in the seafloor and subbottom reflectors suggesting recent deformation.



Active Faults Offshore Mayaguez

Figure 3. A. Sidescan sonar mosaic of shallow insular shelf offshore the city of Mayaguez. Areas of high reflectivity (e.g. scarps, coarse grain sands, hardbottoms) are dark, areas of low reflectivity (e.g. muds, fine grain sands) are light grey. Earthquake epicenters of ms>3.0 from the NEIC are plotted as filled green circles. Onland lineaments identified by SLAR data are shown as thin black lines. Two active fault scarps are clearly visible in the mosaic: Both are NW trending, one extends from Punta Guanajibo across the mosaic, the other bounds the Mayaguez Canyon to the North. B. The high-resolution seismic profiles J'-J and K'-K were collected simultaneously with the sidescan sonographs and show the relative amount of vertical offset on the southern fault.

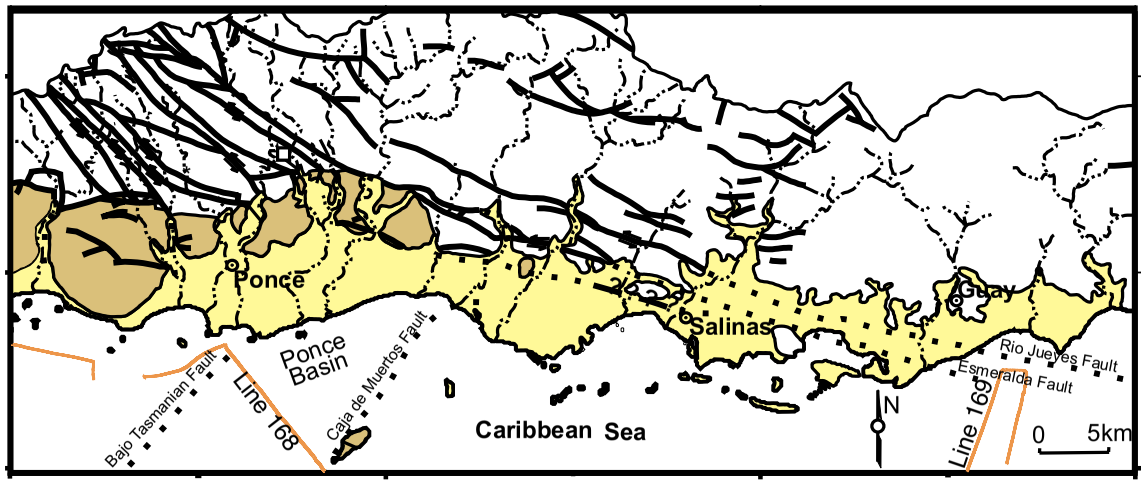




Active Faults Identified on the Southern Insular Shelf

Figure 4. A. A geologic map of southern Puerto Rico. Yellow areas indicate Quaternary aluvium; tan areas are outliers of pre-Quaternary rocks. Onland fault identification from a report prepared by Glover,1971. Tracklines of the May 2000 marine geophysical cruise are shown as thin orange lines. Lines 168 and 169 cross active fault zones on the insular shelf that can be traced to active faults identified onland. Ponce is the second largest city in Puerto Rico. B. High-resolution seismic profiles from Line 168 as it crosses the NE trending Bajo Tasmanian Fault and Caja de Muertos Fault. C. High-resolution seismic profiles from Line169 as it crosses the SE trending Esmeralda Fault and a previously unidentified fault that parallels the Esmeralda and Rio Jueyes faults.

A.



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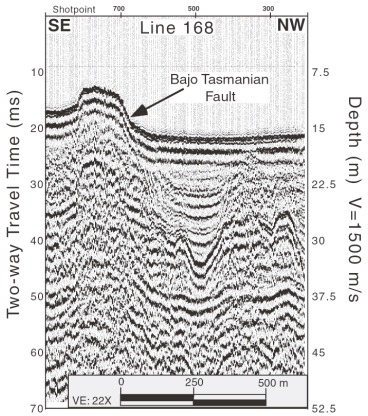

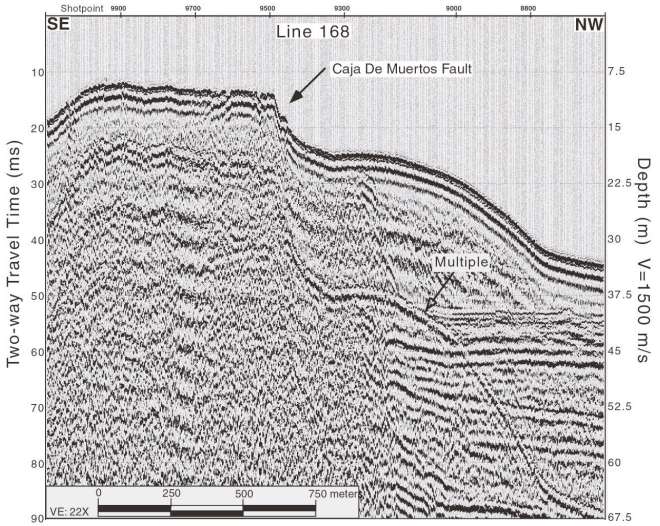

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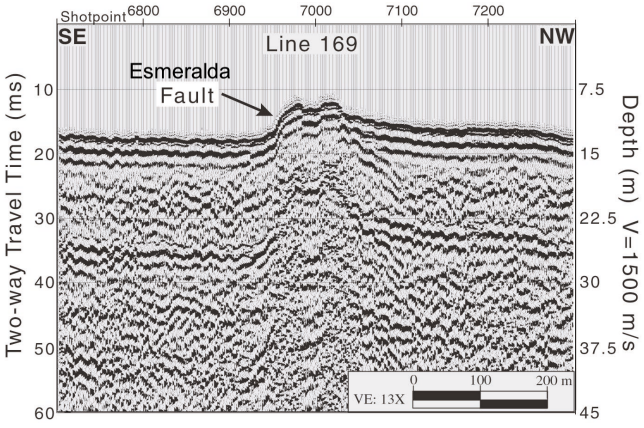

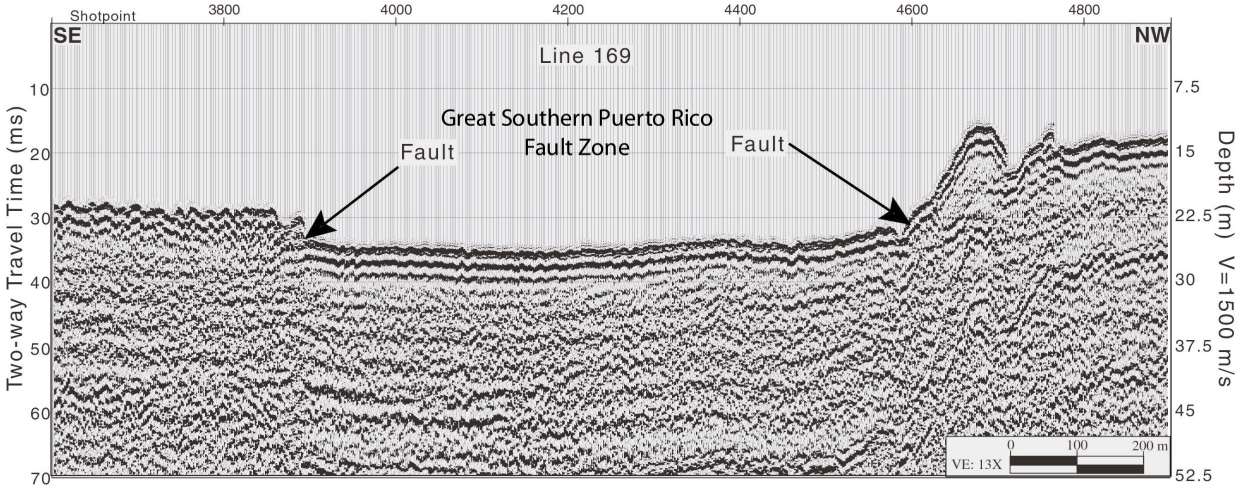

Results and Significance of the Survey

On the basis of previous marine geophysical studies as well as the recent NEHRP-funded onland and marine studies it is becoming increasingly apparent that the deformational history of Puerto Rico and vicinity is very complex. One result of our offshore survey and the coordinated onland trenching and mapping studies (Prentice et al., 2000; Lao et al., 2000) is to show that areas of late Holocene faulting are widespread through the west and south coasts, and that many of these faults appear to reactivate older WNW trending basement structures. It is likely that the style, geometry and distribution of active faults within the Mona Passage and southwestern PR are a function of at least three separate and sequential phases of deformation. The first phase is an Eocene age transpressive event focussed along two major shear zones the Great Northern Puerto Rico Fault Zone and Great Southern Puerto Rico Fault Zone (Erikson et al., 1990, Fig. 1). The second phase of deformation occurred in response to a post-early Pliocene convergence between the North America and Caribbean plates (Van Gestel et al., 1998). The proposed regional arching has an axis that extends in a E-W sense from eastern Hispaniola through the Mona Passage and across the Island of Puerto Rico. This deformational phase would result in many small active faults with a range of orientations distributed over the entire arch and a wide distribution of E-W trending normal faults. The recent extension in the Mona passage and possibly southwestern Puerto Rico as Puerto Rico pulls away in a ENE motion from a pinned Hispaniola could then be accommodated by reactivation of NW trending normal faults or shear zones developed during the first two deformational phases. Thus, the seismic hazard would be associated with the NW faults rather than long NS faults, which have been used in tsunami models for the region (Mercado and McCann, 1998) or/and long left-lateral strike-slip faults.

Future work involves integrating lower-resolution, but deeper penetrating, MCS data with the high-resolution single-channel data into a GIS database, to separate these deformational events, as well as identify areas of preexisting weakness in the basement that could be reactivated and serve to localize present-day deformation.

In summary, both the offshore and onland studies have documented for the first time late Holocene deformation associated with a broad zone of deformation in the Mona Passage and western and southwestern Puerto Rico. Seismic activity associated with crustal deformation produced by the faults imaged offshore western and southern Puerto Rico and with probably other unrecognized structures creates a hazard for one of the densest populations of the western hemisphere in Puerto Rico.

Non-Technical Summary

The main objective of the mapping program was to identify and characterize active faulting on the insular shelves of western and southern Puerto Rico and to link these offshore faults with active faults onland. These results confirm the presence of seafloor scarps interpreted to be late Holocene in age along the trends of the Cerro Goden, Mayaguez, and Great Southern Puerto Rico Fault zones. Both the offshore and onland studies have documented for the first time late Holocene deformation associated with this broad zone of deformation in the Mona Passage and western and southwestern Puerto Rico. The results of this study will provide information about

fault activity needed to further refine earthquake hazard maps of this densely populated region being complied by the US Geological Survey.

Reports Published

We have presented the preliminary interpretation of these data at the 2000 Fall American Geophysical Union meeting (DelGreco et al., 2000; Grindlay et al., 2000; Lao et al., 2000; Prentice et al., 2000), at the International Conference on Seismic Risk Reduction in the Caribbean Region (Mann et al., 2001) and are in the process of writing up these results to be incorporated in a special volume of *Tectonophysics* addressing neotectonics of the northeastern Caribbean region to be edited by Paul Mann and Carol Prentice.

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Contact Information and Data Availability

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